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April 29, 2021

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Quarterly Progress Report for the Period of January 1 – March 31, 2021, "Produced Water Management Through Geologic Homogenization, Conditioning, and Reuse" Contract No. G-051-010

Attached please find the Energy & Environmental Research Center (EERC) Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5421 or by e-mail at kglazewski@undeerc.org.

Sincerely,

DocuSigned by:
DFF46D8431F8412...

Kyle A. Glazewski
Senior Analyst

KAG/kal

Attachment

c/att: Michael Holmes, Lignite Energy Council
Brent Brannan, North Dakota Industrial Commission (NDIC) Department of Mineral Resources, Oil and Gas Division

c: Paul Arnason, EERC

PRODUCED WATER MANAGEMENT THROUGH GEOLOGIC HOMOGENIZATION, CONDITIONING, AND REUSE

Quarterly Technical Progress Report

(for the period January 1 – March 31, 2021)

Prepared for:

Karlene Fine

North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Contract No. G-051-010

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April 2021

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EXECUTIVE SUMMARY

The Energy & Environmental Research Center (EERC), in partnership with the North Dakota Industrial Commission Oil and Gas Research Program, the U.S. Department of Energy, and Nuverra Environmental Solutions (Nuverra), will assess the techno-economic viability of using the Inyan Kara Formation as a geologic solution for produced water treatment and recycling. This Stage I effort will investigate this new approach, herein referred to as geologic homogenization, conditioning, and reuse (GHCR), to managing produced water while simultaneously addressing oil and gas industry challenges related to the management of increasing volumes of produced water and resulting pressurization of geologic formation use for saltwater disposal. GHCR takes advantage of natural processes occurring in the subsurface (such as dilution, mixing, and filtering) to improve produced water quality prior to extraction for subsequent reuse. The GHCR concept represents a nontraditional and potentially transformational approach to produced water management. The benefits of the concept include using existing infrastructure and industry practices, enabling large-volume subsurface storage of produced water, displacing freshwater demand within the industry, and reducing the magnitude and rate of pressurization of the target formation. This progress report represents an update of the Produced Water Management Through Geologic Homogenization, Conditioning, and Reuse activities from January 1 through March 31, 2021.

The initial laboratory-scale column study, which acted as a control experiment, was completed following confirmation that concentrations of the parameters evaluated in samples collected from the exit of the laboratory column had reached a plateau. The simulation model was successfully calibrated with the laboratory data and confirms the observations from the laboratory column test. Simulation results showed a good match for ions and TDS concentrations compared with the water samples from the laboratory column test. A techno-economic framework was developed for applying GHCR to provide the water needed for new oil well stimulation. The framework includes the initial investment needed for conventional oil well stimulation using freshwater and two options that use recycled water supplied by a GHCR production well. Initial techno-economic assessment results suggest that the GHCR concept can be competitive with conventional practice based on fresh water.

The EERC holds an unwavering commitment to the health and well-being of its employees, partners and clients, and the global community. As such, precautionary measures have been implemented in response to COVID-19. Staff continue to carry out project-related activities remotely, and personnel supporting essential on-site laboratory and testing activities are proceeding under firm safety guidelines. Travel has been minimized, and protective measures are being undertaken for those who are required to travel. At this time, work conducted by EERC employees is progressing with minimal disruption. Challenges posed by economic variability will be met with open discussion between the EERC and project partners to identify solutions. The EERC is monitoring developments across the nation and abroad to minimize risks, achieve project goals, and ensure the success of our partners and clients. In the event that any potential impacts to reporting, scope of work, schedule or cost are identified, they will be discussed and addressed in cooperation with the project partners.

PRODUCED WATER MANAGEMENT THROUGH GEOLOGIC HOMOGENIZATION, CONDITIONING, AND REUSE

ACCOMPLISHMENTS

Major Goals of the Project

The Energy & Environmental Research Center (EERC) was awarded a contract by the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) (NDIC No. G-051-101) to conduct a study on the recycling of water used in oil and gas operations, also known as produced water, from oil- and gas-producing regions of North Dakota as directed by Section 19 of North Dakota House Bill 1014. The EERC, in partnership with the NDIC OGRP, the U.S. Department of Energy (DOE), and Nuverra Environmental Solutions (Nuverra), will assess the techno-economic viability of using the Inyan Kara Formation as a geologic solution for produced water treatment and recycling, with the added benefit of providing a potential solution to pressurization of the Inyan Kara Formation in North Dakota. This update is for January 1 through March 31, 2021.

This Stage I effort will provide data on current methods for produced water treatment and recycling and assess the commercial viability of geologic homogenization, conditioning, and reuse (GHCR) for produced water management. In addition to developing and compiling data regarding produced water management methods, the subtask investigates a new approach to managing produced water while simultaneously addressing oil and gas industry challenges related to the management of increasing volumes of produced water and pressure increases in the Inyan Kara Formation. If successful, the GHCR concept offers an attractive technological and economic solution for managing produced water through 1) incorporating existing industry practices and infrastructure to homogenize and condition produced waters for subsequent treatment and/or reuse; 2) enabling large-volume storage and a virtually limitless supply of consistent-quality produced water for subsequent beneficial reuse, displacing freshwater demand and thereby providing assurance of future water supply; and 3) reducing the net volume of saltwater disposal (SWD), thus reducing the magnitude and rate of pressurization of the target disposal formation, extending the life of SWD wells, and reducing oil and gas development costs associated with Inyan Kara pressurization.

The project goal is to assess the techno-economic viability of using the Inyan Kara Formation as a geologic solution for produced water treatment and recycling. Specific research objectives related to this goal are as follows:

- Evaluate produced water management methods, trends, and costs; capacity of water supply and disposal facilities; and economic, regulatory, and technological considerations for water recycling and reuse applications relevant to Bakken produced water management.

- Aim to replicate the interaction between Bakken produced water and the Inyan Kara Formation through laboratory experiments.

- Simulate the performance of the GHCR concept using geologic and geochemical models.

- Assess the techno-economic viability of the GHCR concept, including the relevant economic, regulatory, scientific, technological, and feasibility considerations affecting potential commercial adoption of GHCR.

Accomplishments under These Goals (for the reporting period)

Activity 1.0 – Produced Water Assessment

All activities under Activity 1.0 were completed September 30, 2020.

Activity 2.0 – Field and Laboratory Validation

The initial laboratory column test ran through February 16, 2021, following confirmation that concentrations of the parameters evaluated had reached a plateau. Injection of Bakken produced water into the test column containing sand saturated with synthetic Inyan Kara brine has been ongoing since September 23, 2020, with 146 days of injection throughout the test. The injection rate was set to achieve a flow-through residence time of 36 days to mimic model estimates of field conditions for Bakken produced water being injected into, migrating through, and subsequently extracted from the Inyan Kara Formation at the Best Extraction and Storage Test (BEST) field site.

Brine samples exiting the column were collected daily, with the exception of weekends and when the column was offline for maintenance. Fluid conductivity analysis was performed on each collected sample. A complete set of parameters were analyzed for an additional subset of three samples collected this quarter from the column exit. Previously, this was performed on a subset of five samples collected from the column exit, a sample of the synthetic Inyan Kara brine used to saturate the column, and the Bakken produced water being injected into the column. The complete set of parameters are pH, total dissolved solids (TDS), density, sodium, potassium, calcium, magnesium, strontium, chloride, bromide, sulfate, aluminum, iron, boron, barium, lithium, manganese, phosphorus, zinc, total suspended solids (TSS), and total organic carbon (TOC).

Observations indicate breakthrough of injected Bakken produced water occurred on Day 18 at the column exit as evidenced by the sustained shift and plateau of conductivity (Figure 1). Initial observations indicate the GHCR test column is effectively filtering TSS as evidenced by the consistently low (ranging from <10 to 50 mg/L) TSS in the samples collected at the exit of the column relative to the 180 mg/L TSS measured for the Bakken produced water being injected into the column. This result provides evidence the packing of the column is sufficient and that there are no high-permeability fast-flow pathways present in the column that could contribute to nonrepresentative results.

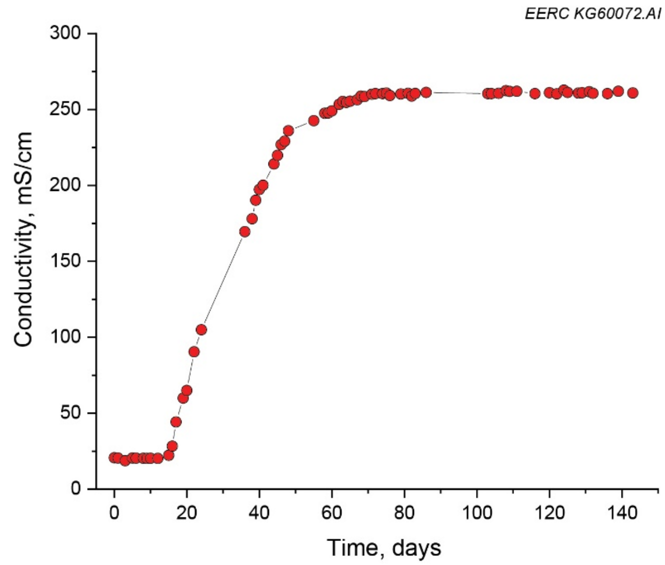

Figure 1. Conductivity measurements of laboratory column test outlet fluid samples. Results indicate that breakthrough of injected Bakken produced water occurred on Day 18, with a reading of 22.3 mS/cm.

With the exception of sulfate (Figure 2), other major analytes are trending with conductivity and TDS (Figure 3), providing data on the volumetric (pore-volume basis) efficacy of the GHCR process relative to flow rate. The TDS, conductivity, and sulfate values are used to calibrate reservoir simulation models. TOC increases over time but at a lower rate than the other analytes (Figure 4). The observed trends in sulfate and TOC are potentially indicative of bacteria and are being evaluated.

Since sulfate was showing a reducing trend, BART (biological activity reaction test) biodetector test kits were used to evaluate whether sulfate-reducing bacteria were present in samples collected from the laboratory column test. The five samples tested were a blank, the synthetic Inyan Kara brine, and three column outlet samples collected at 1-month increments. No presence of these bacteria was noted, indicating that sulfate-reducing bacteria are not likely the cause for the reduction in sulfate. The changing chemistry of the injected brines (i.e., reductions in sulfate and other organic constituents) may be from geochemical reactions, which is still under investigation in the modeling activities under Activity 3.0.

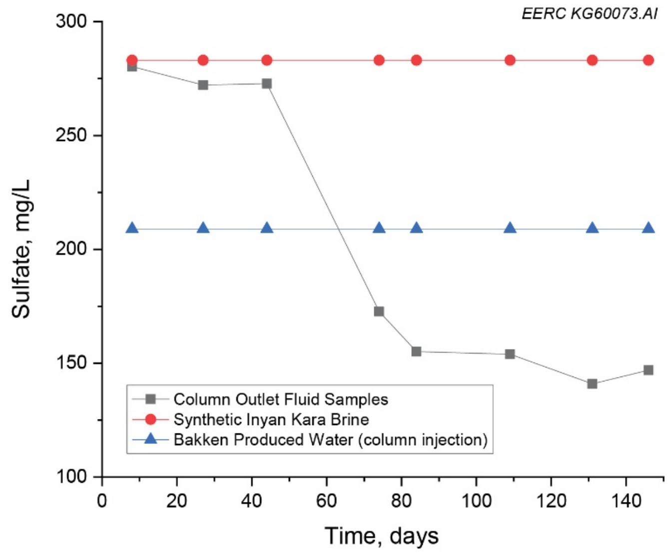

Figure 2. Sulfate measurements of laboratory column test samples (synthetic Inyan Kara brine used to saturate the column, Bakken produced water injected into the column, and fluid samples collected from the column outlet). Reduction of sulfate over time could be indicative of chemical reactions occurring within the system.

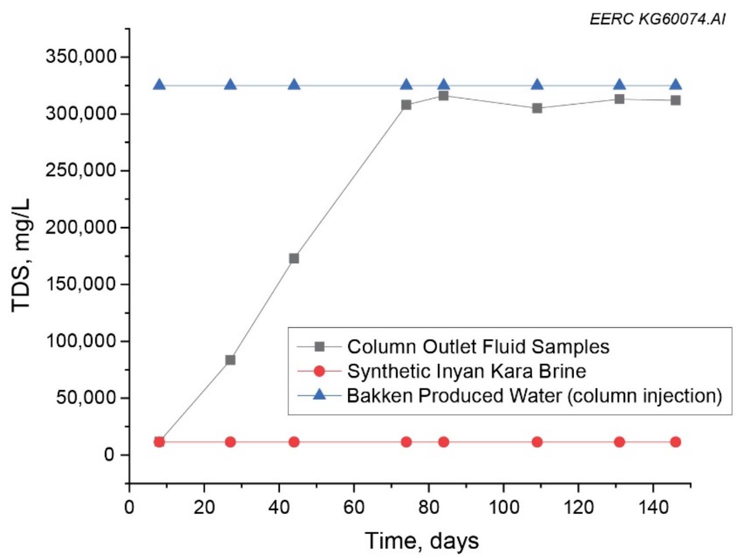

Figure 3. TDS measurements of laboratory column test samples (synthetic Inyan Kara brine used to saturate the column, Bakken produced water injected into the column, and fluid samples collected from the column outlet). Gradual increase of TDS provides an indication of injected Bakken produced water breakthrough at the column outlet and efficacy of the GHCR process.

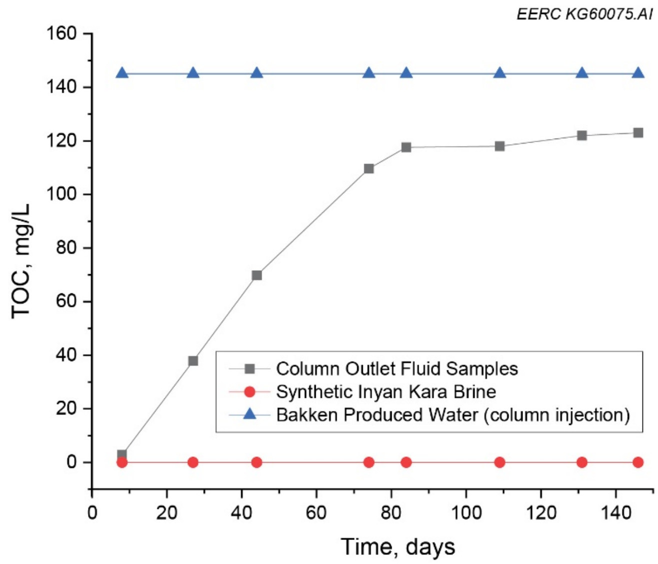

Figure 4. TOC measurements of laboratory column test samples (synthetic Inyan Kara brine used to saturate the column, Bakken produced water injected into the column, and fluid samples collected from the column outlet). The lower rate of increase in TOC could be indicative of chemical reactions occurring within the system.

The next step in the column study is to understand the reactions taking place between the injected Bakken produced water, the native Inyan Kara Formation water, and the formation material (rock). The initial column test evaluated injected Bakken produced water with synthetic Inyan Kara Formation water and a quartz sand to replicate Inyan Kara sand filtering. This initial column test acted as a control experiment, evaluating the filtration efficacy of the sand and any reductions that occur through bacteria development in the produced water/formation matrix. The next stage of laboratory testing will evaluate the interactions between the fluids and actual Inyan Kara material, via core samples, through core flow-through testing. This stage of laboratory testing will evaluate the geochemical reactions that are taking place between the produced water and the rock material. Early indications from geologic model efforts predict reduction in constituents should occur and will be confirmed with the additional testing. For an additional comparison to complement the initial column test, a second column study using Inyan Kara outcrop material (instead of quartz sand) will be set up for an evaluation of the aforementioned interaction of fluids (produced water and Inyan Kara water) and Inyan Kara material. The analyses will inform the efficacy of the GHCR concept at the laboratory scale and will help calibrate the predicted rate of homogenization and filtering taking place through the Inyan Kara material and formation water.

Materials were ordered for updating the column testing apparatus for this next stage of laboratory column testing. The identification of publicly available sample collection locations for obtaining Inyan Kara material was coordinated with the South Dakota state geologist. Identification of Inyan Kara core material was initiated with the North Dakota Core Library.

Activity 3.0 – GHCR Treatment Simulation

A laboratory-scale numerical simulation model was calibrated based on the experimental data from the laboratory column in Activity 2.0. The simulation results were compared with the water chemistry samples obtained from the column test at different dates. The BEST-E1 well water sample data and Bakken produced water were used to validate and calibrate the field model.

The simulation model was calibrated with the laboratory data and confirms the observations from the laboratory column test. Simulation calibration results were matched for the different ions and the TDS concentrations compared with the water samples from the laboratory column test. All the ions, with the exception of sulfate (SO_4^{2-}) and bicarbonate (HCO_3^-), showed a gradual concentration increase as a function of time. This increase was also noted with TDS. Sulfate and bicarbonate show a decreasing tendency, shown in Figure 5, that suggests that chemical reactions into the column can be occurring because of the interaction of the injected Bakken produced water on the native Inyan Kara Formation water. The successful simulation calibration confirms that the simulation model can be matched to the laboratory results, which will allow for the evaluation of different GHCR scenarios to aid in the techno-economic assessment of the GHCR concept. This particular simulation allows for the evaluation of the interaction of Bakken produced water with Inyan Kara Formation water and basic sand filtration, independent of any chemical reactions with the Inyan Kara rock material. Future simulation model development will include field-scale calibration and analysis of the interaction of the fluids and Inyan Kara material as described in Activity 2.0 laboratory testing.

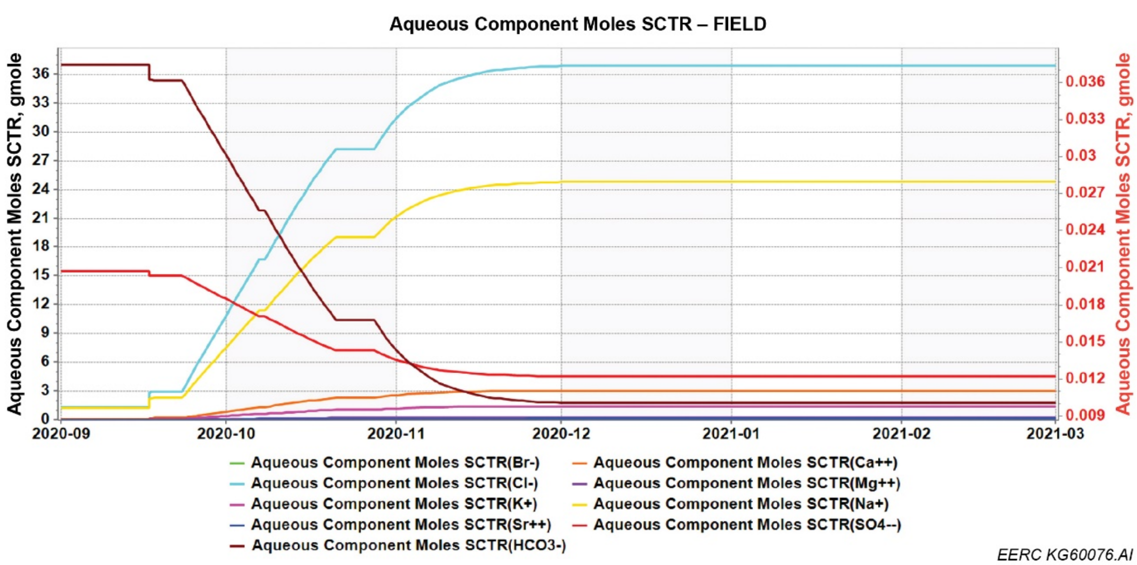

Figure 5. Simulation results representing the ion concentration from laboratory column experiment calibration. A gradual increase of the ion concentration from the production is observed except for sulfate (SO_4^{2-}, red line) and bicarbonate (HCO_3^-, brown line).

Activity 4.0 – Techno-Economic Assessment

A techno-economic framework was developed for applying GHCR to provide the water needed for well stimulation. The framework incorporates initial investment needed for Bakken well stimulation using fresh water and two options that use recycled water supplied by a GHCR production well. The two sets of GHCR assumptions represent cases where a new GHCR well is drilled and one where an existing SWD well is converted into a GHCR production well.

While the techno-economic assessment results are preliminary, initial observations suggest that the GHCR concept can be competitive with conventional practice based on fresh water. However, such conclusions are sensitive to the development cost for the GHCR alternative and its expected lifetime. The more oil wells that a single GHCR well can support, the more favorable it becomes. Ultimately, these lifetime assumptions will be based on the evaluations in Activities 2.0 and 3.0. Further techno-economic assessment will be conducted for a range of scenarios during subsequent quarters.

Plan for the Next Reporting Period to Accomplish the Goals

The next laboratory column studies will be initiated. All materials to update the apparatus will be procured, and the apparatus will be assembled. Inyan Kara core material will be identified and obtained. Team members will travel to South Dakota to obtain Inyan Kara outcrop material, which will then be crushed and sized for use in the column.

Quarterly sampling of the BEST-E1 well will resume once the site is returned to operation, which is anticipated summer 2021 when the extraction well is brought back online.

Mineral rock information will be added into the laboratory-scale simulation model to better understand the different chemical reactions that may take place because of the interaction between the two different waters (the Bakken produced water and the native Inyan Kara water) with the Inyan Kara Formation rock that will be used in the next laboratory column studies. This will aid in the evaluation and prediction of the aqueous reactions and mineral dissolution and/or precipitation that may occur during the water injection/production process in order to better understand the different mechanisms (dissolution, dilution, filtration, etc.) that may have an effect on the water composition.

Key Activity 4.0 activities planned for the next reporting period include refining the techno-economic assessment sensitivity studies using findings from Activities 2.0 and 3.0 and expanding the techno-economic assessment framework to compare ongoing operational costs associated with produced water disposal and well maintenance water. These operational costs can be a significant fraction of the oil revenue on a per barrel basis, and this aspect of the techno-economic assessment will explore potential advantages that GHCR may offer.

CHANGES/PROBLEMS

The EERC is operational and open for business. Personnel that are not essential for on-site operations have transitioned to working from home. Essential project, laboratory, and field-based activities are proceeding with the incorporation of the Centers for Disease Control and Prevention (CDC), the state of North Dakota, and the University of North Dakota guidelines associated with COVID-19, and mitigation measures have been implemented.

In collaboration with project partners, the EERC is continually assessing potential impacts to project activities resulting from COVID-19 and/or the U.S. economic situation. At the time of reporting, there has been no substantial impact to the project. In the event that any potential impacts to reporting, scope of work, schedule, or cost are identified, they will be discussed and addressed in cooperation with NDIC.

Actual or Anticipated Problems or Delays and Actions or Plans to Resolve Them

The BEST-E1 well has been idled for the winter of 2020–2021 and is scheduled to resume operation in Quarter (Q) 3 of 2021. Quarterly sampling of the BEST-E1 well will resume once the site is returned to operation. This downtime is not anticipated to adversely impact the GHCR project.